BRH/DEP 71-6

PB 198 406

EVALUATION of LITHIUM FLUORIDE for MICROWAVE DOSIMETRY APPLICATIONS

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service

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EVALUATION of LITHIUM FLUORIDE for MICROWAVE DOSIMETRY APPLICATIONS

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John C. Villforth
Director
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PREFACE

The recent increase in the production of microwave power sources, such as microwave ovens, has caused a renewed interest in possible hazards associated with the use of microwave (nonionizing) radiation and in the development of microwave dosimetry systems. This report presents an evaluation of the use of LiF thermoluminescent dosimetry (TLD) material as a dosimeter for microwave radiation at 2450 MHz. The work described herein was performed at the Bureau of Radiological Health's Southeastern Radiological Health Laboratory, Montgomery, Alabama. As a result of the recent reorganization, the personnel at the Montgomery facility who are responsible for this project are now assigned to the Bureau's Division of Electronic Products.

Robert L. Elder, Sc. D.
Director
Division of Electronic Products

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ABSTRACT

The use of LiF thermoluminescent dosimetry (TLD) material as a dosimeter for microwave radiation was evaluated. Teflon discs impregnated with LiF were subjected to saturation exposures (approximately 10^5 R) of gamma radiation, and these irradiated dosimeters were exposed to microwave radiation at 2450 MHz. Analysis of the relative light output data for the treatment groups and the control group (which received no microwave irradiation) indicated that there were no significant differences between groups. Hence, it was concluded that LiF, as used in this study, will not serve as a useful dosimeter for microwave radiation in the 2450-MHz frequency band.

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EVALUATION OF LITHIUM FLUORIDE
for
MICROWAVE DOSIMETRY APPLICATIONS

1. INTRODUCTION

This evaluation was performed in an attempt to study in detail a hypothesized effect of microwave radiation on the light emitted from Teflon discs impregnated with LiF. The Teflon discs were initially exposed to about 10^5 R of gamma-ray radiation and were then exposed to a source of microwave radiation with a frequency of approximately 2450 MHz. In previous research (1) with Teflon discs containing LiF it was hypothesized that a portion of the energy stored in the discs as a result of prior exposure to ionizing radiation would be released when the discs were irradiated in a microwave oven operated in the 2450-MHz ISM band. The observed decrease in the light output of these dosimeters with increasing irradiation times in the microwave oven suggested the possible application of this phenomenon to microwave dosimetry.

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2. EXPERIMENTAL

2.1 MICROWAVE OVEN IRRADIATION OF LiF POWDER ENCAPSULATED IN TEFLON CYLINDERS

In the initial portion of this study, LiF (TLD-100) powder encapsulated in Teflon cylinders was used to investigate the possible dependence of the observed effect on the presence of Teflon in discs similar to those used in reference (1). The relevant electrical properties of Teflon and LiF are presented in appendix A.

Approximately 1 g of TLD-100 powder was exposed to 10^5 R of cobalt-60 gamma radiation and then stored in a desiccator for about three months to allow the two low-temperature glow peaks of TLD-100 to decay. Thus, only the higher temperature peaks would be included in the integrated light output observed when the powder was heated during analysis.

The treated TLD-100 powder was separated into 17 samples of about 45 mg each. The individual samples were enclosed in small Teflon containers and sealed. The control, composed of samples 1-5, received no microwave irradiation.

A microwave oven operating in the 2450-MHz ISM band was preheated for 15 minutes to establish thermal stability in the oven circuitry. A 2-liter glass beaker containing 1800 ml of water was heated in the oven for 15 minutes prior to the irradiation of each experimental group and left in the oven during each irradiation period (final water temperature was 100°C). Samples 6-9 were irradiated for 10 minutes in the microwave oven, samples 10-13 were irradiated for 15 minutes, and samples 14-17 were irradiated for 20 minutes. The average power density in the oven cavity was estimated by colorimetric methods to be approximately 100 watts/cm^2. The details of this calculation are given in appendix B.

As shown in figure 1, the relative light output did not decrease progressively as the microwave irradiation time was increased. The vertical bars through the points represent one standard deviation. On the average, the three experimental groups showed less light output than the control, but they showed no proportional decrease in

relative light output with an increase in microwave oven irradiation time. Student's t tests were performed to ascertain if any of the averages of the relative light output for each experimental group were statistically different from the average of the relative light output of the control group. The calculated t values and the published values for the 95 percent confidence level are listed in table 1. At the 95 percent confidence level there were no significant differences.

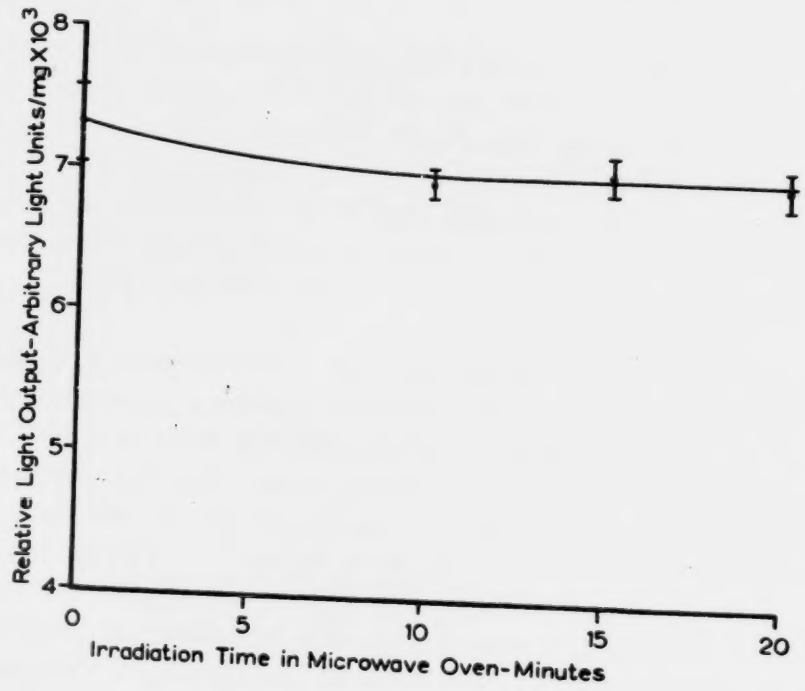

Figure 1. Relative light output of LiF encapsulated in Teflon versus irradiation time in microwave oven.

Table 1. Student's t test comparison of control group of LiF powder encapsulated in Teflon and treatment groups irradiated in a microwave oven.

Treatment group number	$t_{calculated}$
1	1.15
2	0.82
3	1.09

$t_{published}$ for the 95 percent confidence level:

$t_{0.95,7} = 1.90$ and $t_{0.05,7} = -1.90$

Thus, one can conclude that the microwave oven irradiations administered in this experiment did not release a statistically significant portion of the stored energy resulting from a previous exposure to ionizing radiation.

2.2 ANECHOIC CHAMBER IRRADIATION OF TEFLON DISCS IMPREGNATED WITH LiF

Teflon discs (12.7 mm diameter) impregnated with LiF which were identical to those used in reference (1) were used in the remainder of this study. Because the discs differed in their respective sensitivities to ionizing radiation (the range of light output of the individual dosimeters per unit gamma radiation varied by as much as 20 percent), the light output from each dosimeter was multiplied by a correction factor to normalize their sensitivities.

The Teflon discs were separated into four treatment groups, each containing 18 dosimeters, and a control group containing 17 dosimeters. Each of these groups was irradiated with 5×10^5 R of cesium-137 gamma radiation. Following this, the four treatment groups were irradiated with microwave radiation in an anechoic chamber at a power density of 0.6 ± 0.06 mW/cm^2. These irradiations were performed in the far field (using the $2D^2/\lambda$ criterion) with a standard gain horn. The power density in the anechoic chamber was measured with a matching standard gain horn which was supported on a styrofoam stand. This measurement was corroborated by measurements made with a Narda 8100 EMR survey meter and a model 8121A probe. The control group received no microwave radiation. The four treatment groups were exposed to this power density for 5 minutes, 10 minutes, 15 minutes, and 20 minutes, respectively. During exposure in the anechoic chamber each group was fastened to a styrofoam stand which did not detectably alter the microwave field. Subsequent to this microwave exposure, the integrated light output from only the low-temperature peaks of LiF was determined for each Teflon disc. Since the half-life of the main low-temperature peak (105°C) is 10 hours, corrections were made for the spontaneous release of stored energy during the readout procedure which lasted about 2 hours.

No definite effect of microwave irradiation on the relative light output was detected (figure 2). The straight line drawn through the data points in figure 2 in a linear least-squares fit of the data and the data point at 0 irradiation time represents the average of 17 dosimeter readings, whereas the remaining data points represent the average of 18 dosimeter readings. The vertical bars through the points represent one standard deviation.

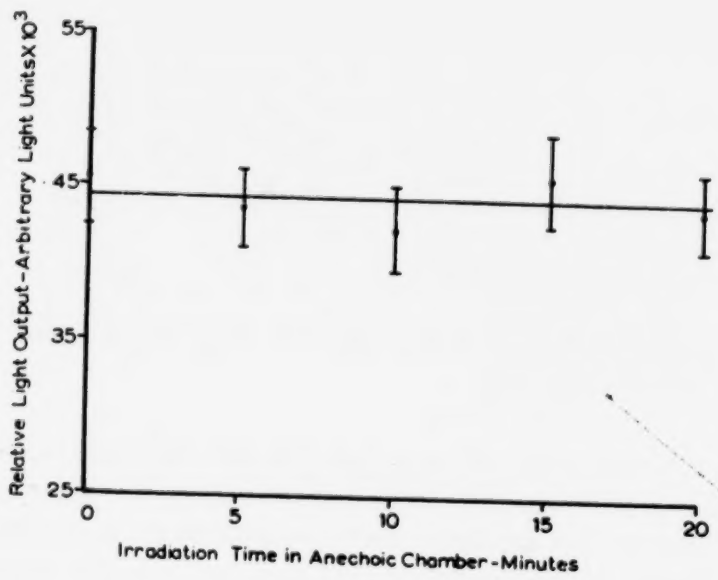

Figure 2. Relative light output of Teflon discs impregnated with LiF versus irradiation time in anechoic chamber.

The data in table 2 show that none of the differences between the mean of the control group and the respective means of the treatment groups are statistically significant at the 95 percent confidence level.

Table 2. Student's t test comparison of control group of Teflon discs impregnated with LiF and treatment groups irradiated in an anechoic chamber.

Treatment group number	t calculated
1	0.269
2	0.012
3	0.886
4	0.249

t published for the 95 percent confidence level:

$t_{0.95,31} = 1.69$ and $t_{0.05,31} = -1.69$

2.3 MICROWAVE OVEN IRRADIATION OF TEFLON DISCS IMPREGNATED WITH LiF

The microwave oven was chosen as the microwave source in the third portion of the experiment. In the preceding portion in which Teflon discs impregnated with LiF were exposed to a power density of 0.6 ± 0.06 mW/cm^2 in an anechoic chamber, no statistically significant reduction in light emission was observed when the dosimeters were read out. Hence, the dosimeters were exposed to the higher power density of a microwave oven in an attempt to produce such a reduction.

Eighty-nine Teflon LiF discs previously given a saturation exposure with approximately 5×10^5 R of cobalt-60 gamma radiation were separated into eight experimental groups of nine dosimeters each and a control group of 17 dosimeters. The microwave oven was preheated for 15 minutes to establish temperature stability within the circuitry of the oven. Each experimental group of nine dosimeters was placed in the oven on a tray with reproducible geometry along with a 1-liter glass beaker filled with 500 ml of tap water. The glass beaker was refilled and the tray was changed for each irradiation of an experimental group to minimize errors caused by changes in

power absorption of the tray (3) and power absorption of the water (4). The following irradiation times in the microwave oven were used for the eight experimental groups: 1/2 minute, 1 minute, 1-1/2 minutes, 2 minutes, 2-1/2 minutes, 3 minutes, 3-1/2 minutes, and 4 minutes, respectively. The control group received no microwave radiation.

After microwave irradiation of the experimental groups, all 89 dosimeters were read out. A random readout procedure was used to minimize any differences in the readings resulting from spontaneous release of light during the readout procedure. The readout instrument was set up so that only the light from the two low-temperature peaks would be recorded. This procedure was adopted because it was thought that the microwave radiation would be more likely to cause reduction of the amplitude of these peaks than it would to cause reduction of the amplitude of the high-temperature peaks.

No marked proportional decrease in the relative light output with increasing irradiation time in the microwave oven was observed. In figure 3 the data point at 0 irradiation time in the microwave oven represents the average of 17 dosimeter readings, and each of the remaining eight experimental group data points represents the average of nine dosimeter readings.

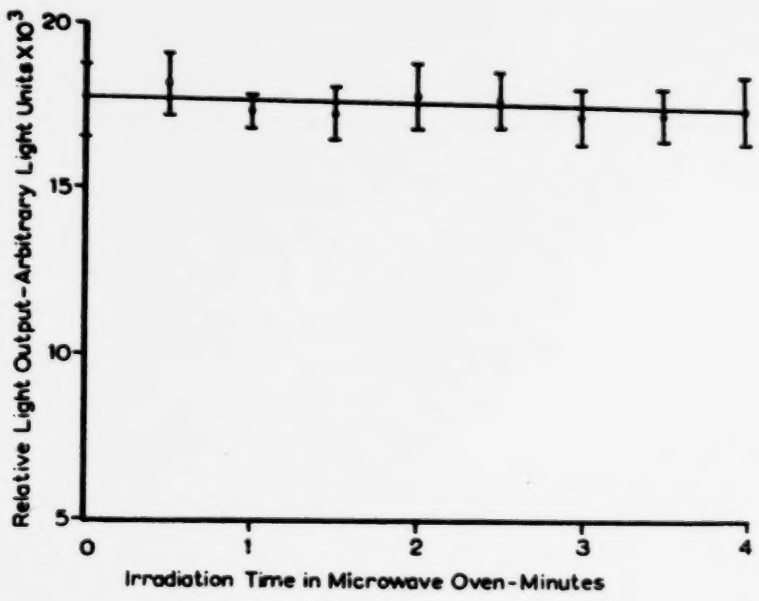

Figure 3. Relative light output of Teflon discs impregnated with LiF versus irradiation time in microwave oven.

The vertical lines through each of the data points in figure 3 represent one standard deviation. Student's t tests were performed on the average readings for the control group and the eight experimental groups. Comparison of the calculated t values and the published t values (table 3) shows that the group responses were not significantly different at the 95 percent confidence level.

Table 3. Student's t test comparison of control group of Teflon discs impregnated with LiF and treatment groups irradiated in a microwave oven.

Treatment group number	$t_{calculated}$
1	0.556
2	0.387
3	0.425
4	0.191
5	0.093
6	0.467
7	0.424
8	0.268

t published for the 95 percent confidence level:

$t_{0.05,24} = -1.71$ and $t_{0.95,24} = 1.71$

3. CONCLUSIONS

The microwave irradiations administered in these experiments did not cause a statistically significant portion of the stored energy in the LiF TLD materials to be released prior to the readout procedure.

These empirical results are supported by the calculations in appendix C. These calculations show that the microwave absorption of both LiF and Teflon are on the order of 0.01 percent of that of water. For the power density used in this study, negligible heating would occur in LiF and Teflon as a result of microwave radiation.

Based upon these findings, research efforts are currently concerned with compounds that can be used as dosimeters of lower photon energy electromagnetic radiation, such as UV and IR radiation. Thermoluminescent compounds, such as ruby and sapphire, which can be used as dosimeters for near-ultraviolet electromagnetic radiation (5) may have some potential application as microwave dosimeters.

Other workers (6) have investigated infrared-sensitive phosphors such as ZnS/Cu, Pb; SrS/Ce, Sm; SrS/Eu, Sm; and SrSe/Eu, Sm. The infrared-stimulated luminescence of the SrSe/Eu, Sm phosphor indicates that it may be more useful than the others as a dosimeter of microwave radiation.

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APPENDIX A

ELECTRICAL PROPERTIES OF TEFLON AND LITHIUM FLUORIDE

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APPENDIX A

Electrical Properties of Teflon and Lithium Fluoride*

Teflon (Polytetrafluoride - DuPont) Properties

@ 22°C & $3GH_z$

Relative Dielectric Constant $(\varepsilon'/\varepsilon_0) = 2.1$

Loss tangent $(\tan \delta) = 1.5 \times 10^{-4}$

Lithium Fluoride Properties (Harshaw Company)

@ 25°C & $3GH_z$

Relative Dielectric Constant $(\varepsilon'/\varepsilon_0) \simeq 9.0$

Loss Tangent $(\tan \delta) \simeq 2.0 \times 10^{-4}$

* von Hippel, Arthur R., Dielectric Materials and Applications, The M.I.T. Press, Massachusetts Institute of Technology, Cambridge, Massachusetts, Copyright 1954, pp. 332 and 301.

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APPENDIX B

CALCULATION OF AVERAGE POWER DENSITY IN TAPPAN R-4A MICROWAVE OVEN CAVITY

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APPENDIX B

Calculation of Average Power Density in TAPPAN R-4A Microwave Oven Cavity.*

In my experiment the temperature of 1 liter of water raised 23^0C when heated for 2 minutes in the microwave oven.

Given that:

$$P/V = C_p \rho \Delta T/\Delta t$$

where, P = power

V = volume

C_p= specific heat

ρ= density

ΔT= raise in temperature

Δt= time of heating H_2O

Also $P/V = E^2 K \tan \delta \ \ 2\pi f \varepsilon_0$

where, E = root mean square electric field

K = dielectric constant of material of interest

$\tan \delta$= loss tangent

f = frequency

(ε_0)= dielectric constant of vacuum

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APPENDIX B (continued)

From given data and known constants:

$$P/V = \frac{\left(\frac{1\ cal}{g\ ^0C}\right)\left(\frac{1g}{cm^3}\right)\left(23^0C\right)}{(120\ sec)} = 0.192\ \frac{cal}{(cm^3)(sec)} \quad or \quad 0.804\ W/cm^3$$

since $P/V = E^2 K \tan(\delta)\ 2\pi f(\varepsilon_0)$

or $$E^2 = \frac{P}{(v)(k)\ (\tan\delta)(2\pi f)(\varepsilon_0)}$$

$P/V = 0.804\ W/cm^3$ or $8.04 \times 10^5\ W/m^3$

$$E^2 = \frac{(8.04 \times 10^5\ W/m^3)}{(75)(.14)(6.28)(2.45\ GH_z)(8.85 \times 10^{-12}\ farad/m)}$$

$E^2 = 56.23 \times 10^4\ v^2/m^2$

$E = 7.5 \times 10^2$ V/m (inside H_2O in beaker)

from Page 91 of Principles of Electricity, Page and Adams, for sphere (which short cylinder approximates because width of cylinder ≈ height of water level in beaker)

** $$E_{r.m.s.}\ (inside) = \left(\frac{3}{K+2}\right) E(outside)$$

$$E_{r.m.s.}(outside) = \left(\frac{75+2}{3}\right)(7.5 \times 10^2\ V/m) = 1.925 \times 10^4\ V/m$$

Since water shape while in cylinder is not absolutely spherical:

E(outside)/E(inside) slightly greater than 1.

$\therefore$ $E_{r.m.s.}$ (outside) $\simeq 2 \times 10^4$ V/m.

APPENDIX B (continued)

From Physics for Students of Science and Engineering, Holliday and Resnick, Part II, Page 897.

$$\bar{S} = \left(\frac{1}{\mu_0 c}\right) \bar{E}^2$$

WHERE

$\bar{S}$ = average power density

μ_0 = permeability constant of vacuum

c = speed of light

$\bar{E}$ = average electric field intensity

$\bar{E}^2 = 1/2\ Em^2$ (Em = maximum value of Electric Field)

but $E_{r.m.s.} = (0.707)\ E_m$

$$Em = \frac{E_{r.m.s.}}{0.707}$$

or $\bar{E}^2 = 1/2\ (E_{r.m.s.}/0.707)^2 = (1/2)\ (E^2_{r.m.s.})$ (2)

$$\bar{E}^2 = E^2_{r.m.s.}$$

$$\therefore \bar{S} = \left(\frac{1}{\mu_0 c}\right)\left(E^2_{r.m.s.}\right) \text{ where } \left(\frac{1}{\mu_0 c}\right) = 2.654 \times 10^{-1} \ \frac{\text{amp-sec}}{\text{weber}}$$

where $E_{r.m.s.}$ has units of V/m

and $\bar{S}$ has units of W/m^2

$$\bar{S} = (2.654 \times 10^{-3} \ \frac{\text{amp sec}}{\text{weber}}) \ (4 \times 10^8 \ V^2/m^2)$$

$$\bar{S} = 10.62 \times 10^5 \ W/m^2$$

NOTE: Where 1 weber = 1 (volt) (sec)

APPENDIX B (continued)

or $\bar{S} \approx (10.62 \times 10^5 \text{ W/m}^2) \left(\frac{10^3 \text{ mW}}{\text{W}}\right) \left(\frac{1 \text{ m}^2}{10^4 \text{ cm}^2}\right)$

$\bar{S} \approx 10.62 \times 10^4 \text{ mW/cm}^2$ or 100 Watts/cm^2 in oven cavity

* WHITE, Jerome R., "Measuring the Strength of the Microwave Field in a Cavity," The Journal of Microwave Power, W.A.G. VOSS, Editor, University of Alberta, Edmonton, Alberta, Canada, Volume 5, number 2, July 1970, pp. 145-147.

** Telecon with JEROME R. WHITE on 7 December 70 at Varion Industrial Systems Activity, 611 Hansen Way, Palo Alto, California, 94303, revealed that the E(outside) referred to in his article "Measuring the Strength of the Microwave Field in a Cavity," was Er.m.s. (root mean square.)

APPENDIX C

AVERAGE POWER ABSORBED PER VOLUME OF H_2O, LiF, AND TEFLON

APPENDIX C

Average Power Absorbed per Volume of H_2O, LiF, and Teflon

Since $P(watts/m^3) = (2\pi)(f)(\tan\delta)\left(\frac{\varepsilon'}{\varepsilon^0}\right)(\varepsilon_0)\left(\frac{E_0^2}{2}\right)$ *

@ 3GH$_z$ Loss Tangent ** $\frac{H_2O}{(\tan\delta)} = 0.17$

Relative Dielectric Constant ** $(\varepsilon'/\varepsilon_0) = 72$

$$P = \left(3.33 \times 10^8 \text{ watts/m}^3\right)\left(\frac{1m^3}{10^6 cm^3}\right) = 3.33 \times 10^2 \frac{watts}{cm^3}$$

LiF

From Appendix A:

@ 3GH$_z$ $\tan\delta = 2.0 \times 10^{-4}$

$\varepsilon'/\varepsilon_0 = 9.0$

$P = 4.90 \times 10^{-2}$ watts/cm^3

TEFLON

From Appendix A:

@ 3GH$_z$ $\tan\delta = 1.5 \times 10^{-4}$

$\varepsilon'/\varepsilon_0 = 2.1$

$P = 8.58 \times 10^{-3}$ watts/cm^3

* Page 10, equation (3.17) von Hippel, Arthur R., Dielectric Materials and Applications, The M.I.T. Press, Massachusetts Institute of Technology, Cambridge, Massachusetts.

** White, Jerry R., "Measuring the Strength of the Microwave Field in a Cavity," The Journal of Microwave Power, Volume 5, Number 2, July 1970, Page 146.

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DIVISION OF ELECTRONIC PRODUCTS

Technical Reports

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BRH/DEP 70-16	Near Field Instrumentation (July 1970) (PB 192 748 $3.00)
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